ANALYSIS

Vol. 16, 2019

ISSN 2319–7757 EISSN 2319–7765

Indian Journal of Engineering

Roll motion damping using gyroscopic stabilizers

Ini Akpadiaha[1✉], **Victor Jeremiah**[2]

[1]Department of Marine Engineering, Akwa Ibom State University, Akwa Ibom State, Nigeria
[2]Department of Marine Engineering, Akwa Ibom State University, Akwa Ibom State, Nigeria

✉**Correspondence author**
Department of Marine Engineering, Akwa Ibom State University, Akwa Ibom State, Nigeria
Email: iniakpadiaha@gmail.com

Article History
Received: 06 June 2019
Accepted: 23 July 2019
Published: August 2019

Citation
Ini Akpadiaha, Victor Jeremiah. Roll motion damping using gyroscopic stabilizers. *Indian Journal of Engineering*, 2019, 16, 242-251

ABSTRACT

Of all the motions of the vessel, the roll motion which is the rotation of the vessel about the longitudinal axis is of utmost concern as it has the potential of causing: reduction in ship's velocity, damage of cargo onboard, sea sickness to the crew onboard, prevention of effective usage of equipments onboard, and when intense capable of capsizing and possible loss of ship, investment and death of seamen at large. MV Ofure, a 28 meter long search and rescue boat, fitted with passive anti-rolling fins is employed by the Nigerian maritime administration and safety agency to carry out rescue operations at the Lagos offshore and anchorage area. The vessel often experience difficulty in carrying out swift and timely rescue operation due to the very little roll motion damping offered by the passive anti-rolling fins. The crew onboard experience sea sickness, great reduction in vessel speed when operating at the Lagos offshore and anchorage area, and limitation in maneuverability and station-keeping during rescue operations. Since the operation carried out by this vessel is critical, there is need to provide a lasting and more reliable solution to the roll motion challenge experienced by MV Ofure in the course of discharging her legitimate duties. This article demonstrates the damping of roll motion using gyrostabilizer. The result obtained from the analysis shows that the Veem VG145SD gyrostabilizer installed at 2/3 the length of

the vessel (MV OFURE) is capable of reducing the roll amplitude of the vessel to a value of 1.76° within the roll period of ten seconds in regular and irregular waves.

Keywords: Roll motion; Damping; Gyrostabilizer; MV Ofure; Waves; Stability

1. INTRODUCTION

A ship floating on water under the influence of regular and irregular wave patterns shown in Figure1 will experience six degree of freedom along the three special axis as shown in Figure 2. These special axis are: the vertical axis also known as the z axis or yaw axis, the longitudinal axis also known as the x or roll axis and the lateral axis also known as the y or pitch axis. These six degrees of freedom are subdivided into: translational motion and rotational motion. The translational motions are: heave, surge and sway motion whereas the rotational motion are: pitch, yaw and roll motions respectively.

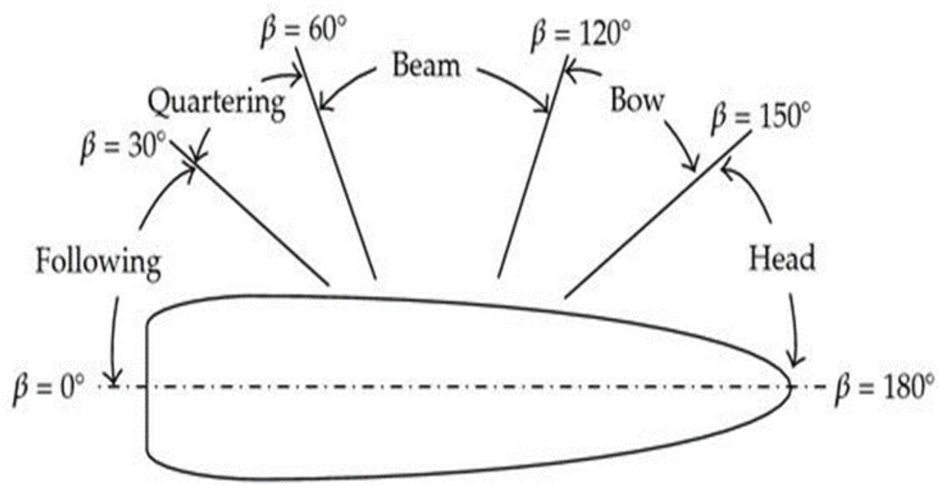


Figure 1 Action of regular and irregular waves on a moving ship (Source: Perez, 2005)

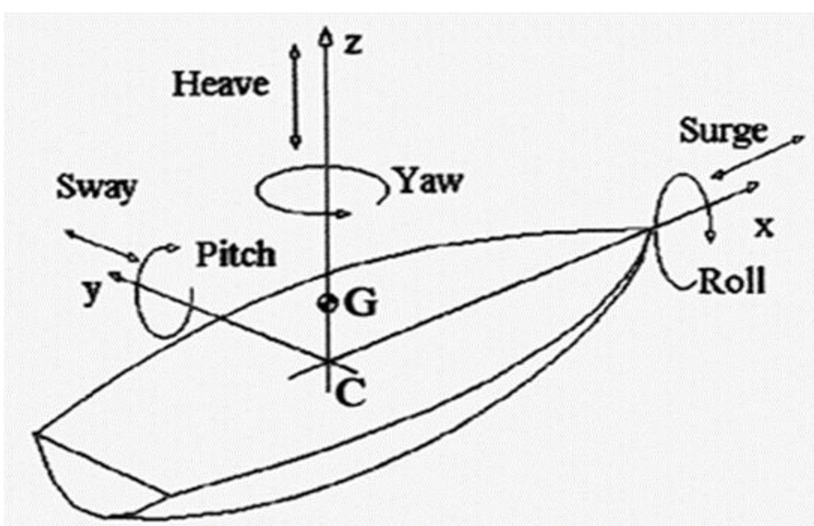


Figure 2 Diagram of a vessel showing the six degrees of movement (Source: Perez and Blanke, 2012)

Of all the motions of the vessel, the roll motion shown in Figure 3 which is the rotation of the vessel about the longitudinal axis is of utmost concern as it has the potential of causing: reduction in ship's velocity, damage of cargo onboard, sea sickness to the crew

onboard, prevention of effective usage of equipments onboard, and when intense capable of capsizing and possible loss of ship, investment and death of seamen at large (Perez and Blanke, 2012).

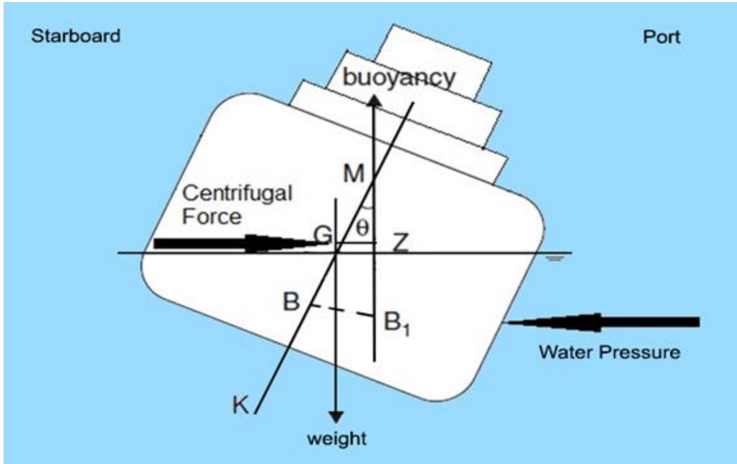


Figure 3 Diagram of vessel showing the effect of roll motion (Source: Arnold and Maunder, 1961).

The drastic effects of roll motion on smooth operation of vessel became noticed in the mid-19th century, when:

- The hulls forms of the vessels changed from broad arranges to turrets.
- Engines replaced sails as means of propulsion.

Naval architects and marine engineers over the years, have taken it upon themselves to dampen the negative effects of roll motion on ships by designing systems to reduce the roll angle, roll accelerations, amplitude of rolling and prolonging the roll period as reported by Tristan Perez (2005)

These systems are passive and active systems. The passive systems use no separate source of power and no special control, they are: Bilge Keel, anti-rolling tanks (passive), fixed fins and passive moving weight systems. The active system work by producing moments to oppose the roll motion aided by moving masses or control surfaces which uses power and special controls, examples are: active fins, moving weight (active) and the gyroscope or gyrostabilizers (Perez and Blanke, 2012).

MV Ofure, a 28 meter long search and rescue boat, fitted with passive anti-rolling fins is employed by the Nigerian maritime administration and safety agency to carry out rescue operations at the Lagos offshore and anchorage area. The vessel often experience difficulty in carrying out swift and timely rescue operation due to the very little roll motion damping offered by the passive anti-rolling fins. The crew onboard experience sea sickness; there is great reduction in vessel speed when operating at the Lagos offshore and anchorage area, and limitation in maneuverability and station-keeping during rescue operations. Since the operation carried out by this vessel is critical, there is need to provide a lasting and more reliable solution to the roll motion challenge experienced by MV Ofure in the course of discharging her legitimate duties. This article aims to demonstrate that the gyrostabilizer is the most effective and reliable anti-rolling device for MV Ofure compared to the passive anti-rolling fins.

2. MATERIALS AND METHODS

After obtaining the particulars of MV Ofure, the veem gyro calculator was used to determine a suitable gyroscopic stabilizer for the vessel considering her principal particulars. The roll amplitude damping capability of the gyroscopic stabilizer in regular and irregular waves was analyzed using the principle of preservation of angular momentum and mathematical models. The principal particulars of MV Ofure and the proposed veem gyroscopic stabilizer specification used for this research work are presented in tables 1 and 2 respectively.

Table 1 Principal Parameters of MV Ofure (NIMASA Brochure, 2008)

Quantity	Value	Unit
Vessel name	MV Ofure	-
IMO number	9221712	-
Type	Search and rescue vessel	-
Max speed	25	Knots

Gross tonnage	117	Tones
Length	28	M
Breadth	6	M
Draft	1.5	M
Natural roll period	7.24	Seconds
Radius of gyration	2.34	M
Transverse Metacentric Height	0.42	M
BM	2.5	M

Table 2 Veem VG145SD Gyroscopic stabilizer particulars (Source: VEEM VG145SD installation manual.)

Quantity	Value	Unit
Rated stabilizing torque	145	KNm
Mass of Gyrostabilizer	3000	Kg
Angular momentum	70	KNs
Power	15	KW
Length	1.6	M
Width	1.56	M
Height	1.15	M
Rated RPM	4800	-
Running noise	67	dBA

Calculation of Righting Lever for the Vessel When Heeled To an Angle Equivalent to the Roll Amplitude (φ)

For small angles of heel (i.e 0<φ<100), the value of the righting arm (G_Z) is calculated using:

G_Z = Gmxsinφ (1)

For large angle of heel (10<φ<∞), the righting lever is calculated using:

G_Z = Gmxsinφ + 0.5Bmxtan2φxsinφ (2)

Where:

Gz = righting lever, metres

Gm = metacentric height of the ship, metres

Bm = vertical distance between the ship's centre of buoyancy and the metacentre, metres.

φ = roll amplitude which is equal to heeling angle, degrees.

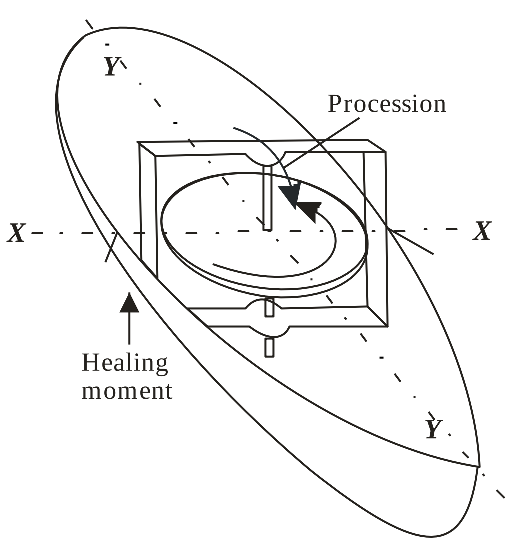


Figure 4 Installation of the gyrostabilizer on the hull of the vessel

Performance Analysis of the Combined Ship and Gyrostabilizer System

The single gyrostabilizer mounted on a single gimbal structure at a position equal to 2/3 of the vessel length illustrated in figure 4 below is analyzed for the ship floating in regular and irregular waves, the roll amplitude reduction capabilities of the gyrostabilizer is computed for the two cases.

Basic Assumptions made

For the purpose of this work, the following assumptions are made in the roll amplitude reduction ability of the gyrostabilizer

- The value of the roll amplitude measured is the mean of the ship's roll amplitude when she is rolling from port to starboard
- The vessel is stiff
- The GMt of the vessel is positive throughout the roll period
- The gyrostabilizer begins to precess after five (5) seconds in the direction opposite the roll excitation torque offered by encountering beam seas.
- The gyrostabilizer begins to precess from maximum precession angle of 60 degrees to minimum precession angle of 10 degrees in five(5) seconds
- The wave period does not coincide with the ship's natural roll period
- The gyrostabilizer is installed at a position equal to 2/3 of the ship's length.
- The gyrostabilizer does not exceed the precession angles of 60 degrees maximum and 10 degrees minimum
- The vessel experiences maximum oscillatory roll excitation of 5°/s in amplitude for regular waves and 10°/s for irregular waves.

Determination of the roll amplitude reduction capability of the gyrostabilizer

The angular momentum (L) of the vessel when she is experiencing roll motion while floating on both regular and irregular wave under the influence of beam seas is expressed as follows:

$$L = \varphi x \frac{2\pi}{T} x I \qquad (3)$$

Where:

φ = mean roll amplitude when the vessel rolls from port to starboard (degrees)

T = ship's natural roll period, measured in seconds

I = moment of inertia of the ship about her rolling axis.

According to IMO intact stability codes (2008),

$$T = 2\pi\sqrt{\frac{I}{\Delta\ x\ g\ x\ Gm}} \qquad (4)$$

$$\text{Therefore, } I = \frac{T^2 \text{ x } \Delta \text{ x g x Gm}}{4\pi^2} \qquad (5)$$

Substituting equation (3.5) in equation (3.3), gives an expression for the angular momentum (L), written as follows:

$$L = \frac{\varphi x \Delta x g x G m x T}{2\pi} \qquad (6)$$

Considering a gyrostabilizer installed onboard the vessel on a single gimbal structure, precessing between $\pm ø_o$, the angular momentum of the gyrostabilizer as it precess along its gymbal axis is expressed as:

$$L_S = 2\int_o^{\emptyset o} N \cos \emptyset d\emptyset \qquad (7)$$

Where,

N =rated value of the gyrostabilizer angular momentum, measured in KNs

Øo = precession angle of the gyrostabilizer, measured in degrees

For the gyrostabilizer to dampen or reduce the roll amplitude of the vessel, the angular momentum of the vessel, must equate that of the gyrostabilizer, therefore equation (6) must be equal to equation (7)

i.e $$\frac{\varphi x \Delta x g x G m x T}{2\pi} = 2\int_{o}^{\emptyset o} N \cos \emptyset d\emptyset \quad (8)$$

Therefore, $$\varphi = \frac{4\pi N Sin\emptyset o}{\Delta . g . Gm . T} \quad (9)$$

Equation (9) above represents the single wave increment of rolling (increase in roll amplitude), which can be dampen by fitting a gyroscope of angular momentum (N).

Where,

Φ	= new roll amplitude resulting from gyroscopic action, in degrees
N	= angular momentum of the gyrostabilizer, KNs
Øo	= Precession angle of the gyrostabilizer, in degrees
Δ	= displacement of the vessel, kg
g	= acceleration due to gravity, m/s2
Gm	= metacentric height of the vessel, metres
T	= roll period of the vessel, seconds

3. RESULT AND DISCUSSION

Roll Amplitude Reduction Capability of the Gyrostabilizer

Effect of The VG145SD Gyrostabilizer on the Roll Amplitude when The Vessel is Floating on Regular Waves under Influence of Beam Seas

The values of the roll amplitude experienced by the vessel when floating on regular waves under the influence of beam seas for 10seconds was determined by the basic assumption made earlier. The values of the righting arm for the vessel at each roll amplitude was calculated with aid of MINITAB17 software as shown in appendix A using equations (1) and equations (2). The roll amplitude reduction ability of the gyrostabilizer was computed with aid of MINITAB 17 software and presented in appendix B using equation (9). The graph in figure 5 was plotted using results obtained.

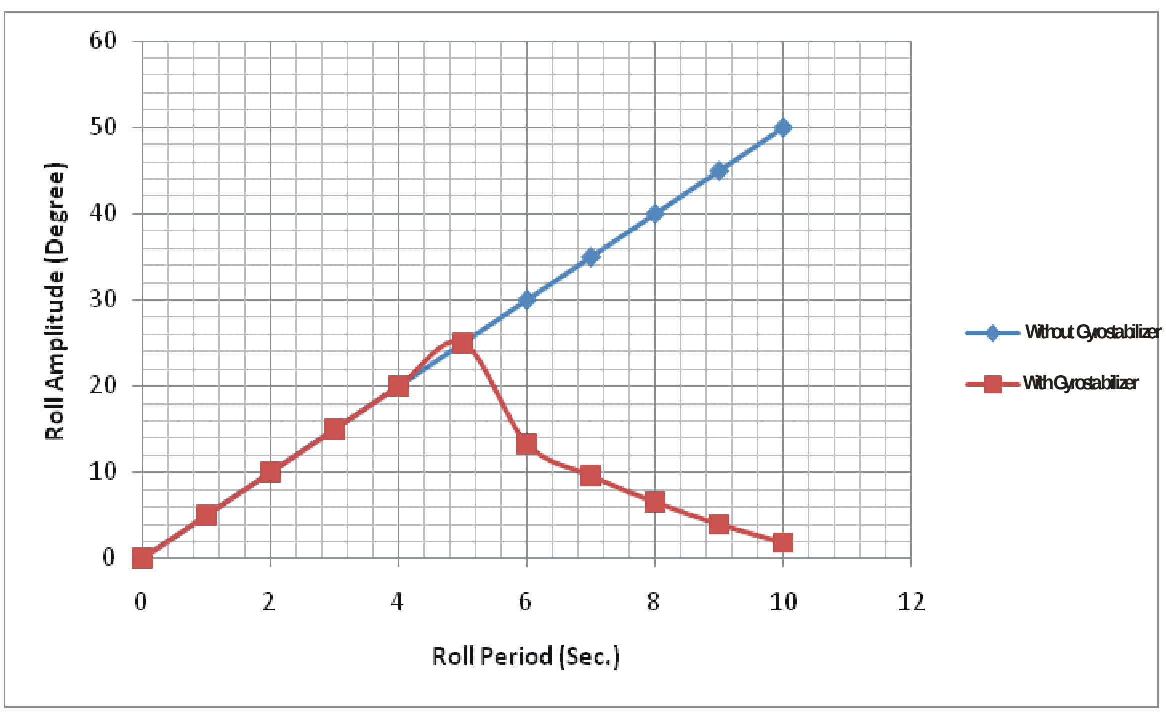


Figure 5 Graph of roll amplitude against roll period when the vessel is floating on regular wave with and without VG145SD - gyrostabilizer

Analysis shows that for every one second increment in roll period, the vessel experience a roll excitation of value equal to five times the roll period. The righting lever required to restore the vessel when heeled to an angle equal to or greater than 30° is greater than the 0.2 metres limit required in the IMO intact stability criterion for vessels less than 100 metres long.

Analysis from second result shows that for the first five minutes of rolling, the gyrostabilizer, precess from 10° to 60° in the direction of the roll excitation torque. It then begin to precess in the opposite direction on reaching its maximum angle of precession (i.e. 60°), where it significantly reduce the roll amplitude to a value of 1.76° in the next five seconds.

From the graph in figure 5, the relation between the roll amplitude and the roll period is linear when no gyrostabilizer is installed onboard the vessel. With the installation of the gyrostabilizer onboard, as indicated by the red line on the graph the roll amplitude suddenly starts to decrease when the gyrostabilizer is activated after five seconds to generate the roll opposing torque and continues to decrease until the gyrostabilizer attains its minimum angle of precession (i.e. 10°)at the end of the roll period.

Effects of VG145SD Gyrostabilizer on Roll Amplitude when the Vessel Floats on Irregular Waves under the Influence of Beam Seas

The values of the roll amplitude experienced by the vessel when floating on irregular waves under the influence of beam seas for 10 seconds was determined by the basic assumptions earlier made. The roll amplitude reduction ability of the gyrostabilizer was calculated with aid of MINITAB 17 software and presented in appendix B using equation 9. The graph in figure 6 was plotted using was plotted using results obtained.

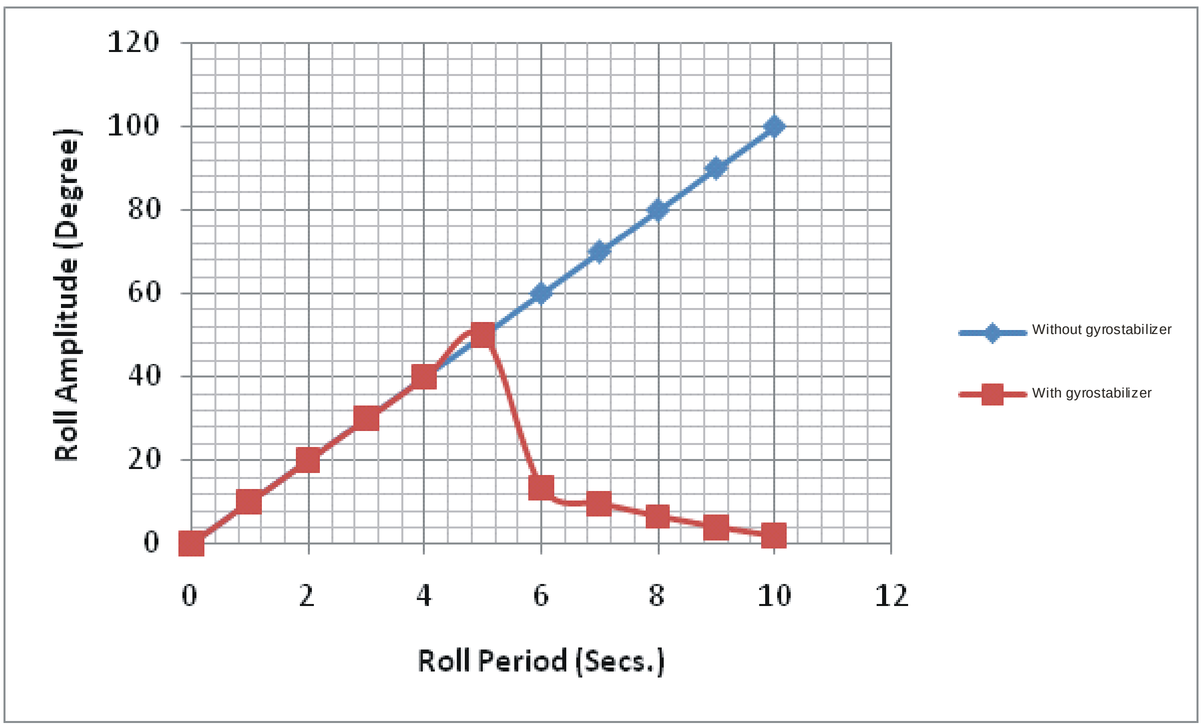


Figure 6 Graph of roll amplitude against roll period when the vessel is Floating on irregular wave with and without VG145SD – gyrostabilizer.

It is observed from results that the roll amplitude increases by a value of 10 for every one second increment in time when the vessel is floating on irregular waves. It is also observed that after five seconds of rolling, the gyrostabilizer attends its maximum angle of precession and travels counter clockwise to the direction of the roll excitation torque and within five seconds precess to an angle of 10° with a significant roll amplitude reduction to 1.76°.

The relation of the roll amplitude with roll period from the graph in figure 6 is linear when no gyrostabilizer is installed and starts decreasing with increase in roll period when the installed gyrostabilizer starts precessing five seconds into the roll period and continues to decrease to its minimum value as the gyrostabilizer attains its minimum angle of precession at the end of the roll period.

4. CONCLUSION

At the end of the research work, the following conclusions were drawn:

A ship sailing or floating on regular and irregular waves under the influence of beams will experience roll motion about its longitudinal axis with roll amplitudes of 50° and 100° respectively after five minutes of rolling in regular and irregular waves.

The roll amplitude if not damped or reduced to acceptable limit has the potential to reduce the ship speed, damage cargoes onboard, cause sea sickness to seafarers and passengers onboard, prevent effective use of shipboard equipment and capsizing of vessel.

The result obtained from the analysis shows that the Veem VG145SD gyrostabilizer installed at 2/3 the length of the vessel (MV OFURE) is capable of reducing the roll amplitude of the vessel to a value of 1.76° within the roll period of ten seconds in regular and irregular waves.

The performance of the gyrostabilizer is not affected by the sea state if effective control systems are installed to maintain the precession rate.

The gyrostabilizer is not vulnerable to damage by external factors.

The outstanding performance offered by the gyrostabilizer in regular and irregular waves makes it most effective anti-rolling device compared to passive anti-rolling fins with 30% roll reduction capability and also very vulnerable to damage by external factors.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

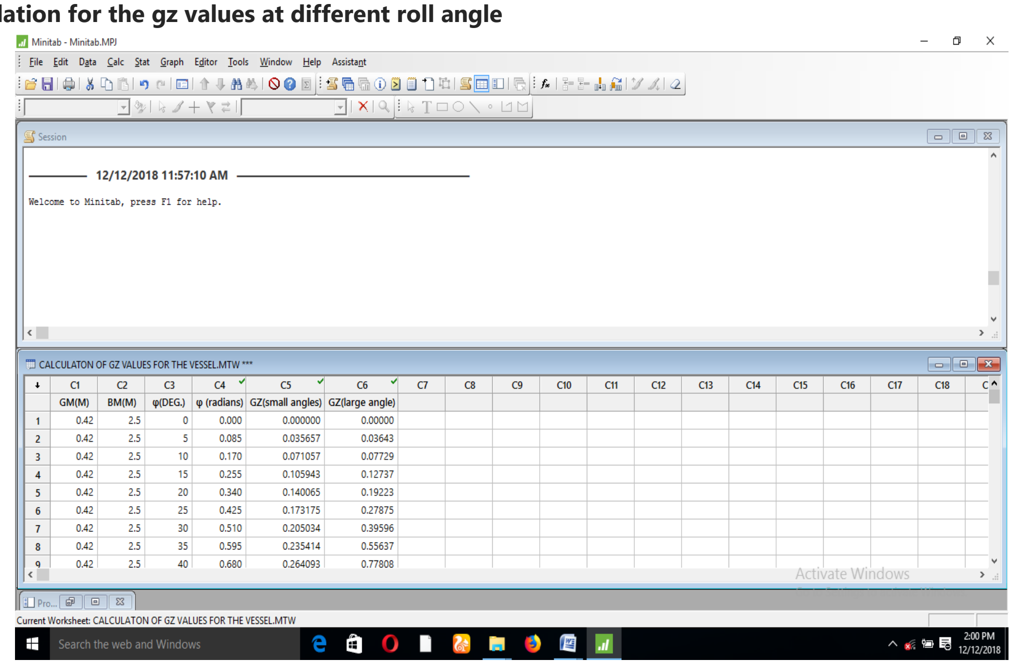
Authors' biography

Ini Akpadiaha gained his MSc in Marine Engineering Management from the University of Greenwich, UK and his Bachelors Degree in Chemical Engineering from Federal University of Technology, Owerri in Nigeria in 2010 and 2006 respectively. He is currently a Lecturer at the Akwa Ibom State University and his main research interests are related to Ship Emissions, NOx, SOx and PM abatement technology in Ships, Computational Fluid Dynamics, Ship Safety and Ship Pollution

Victor Jeremiah obtained his Ordinary Natiional Diploma in Ship Building Technology from the Maritime Academy, Oron in Nigeria in 2009 and a first class Bachelors degree in Marine Engineering from the Akwa Ibom State University in 2019. He currently runs a manning company, Hellibill Nigeria Limited and is a research assistant for Trimen Engineering Firm. He is passionate about Hydrodynamics and ship strength and structures.

Appendix A

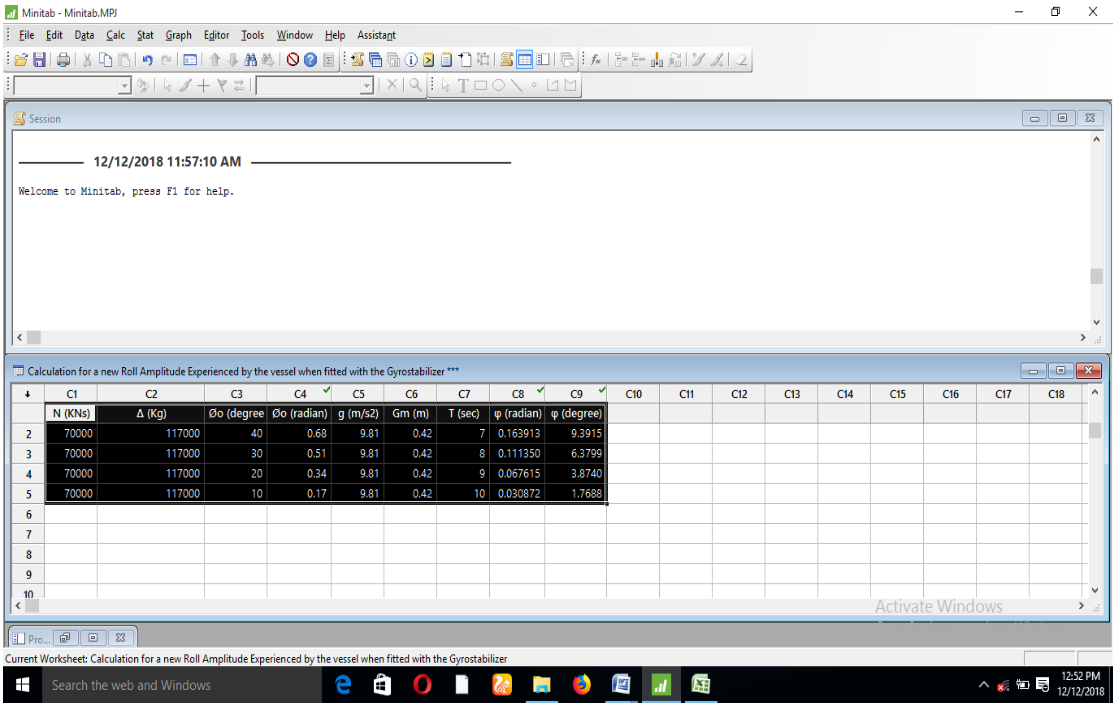
Minitab 17 calculation for the gz values at different roll angle



↓	C1	C2	C3	C4	C5	C6
	GM(M)	BM(M)	φ(DEG.)	φ (radians)	GZ(small angles)	GZ(large angle)
1	0.42	2.5	0	0.000	0.000000	0.00000
2	0.42	2.5	5	0.085	0.035657	0.03643
3	0.42	2.5	10	0.170	0.071057	0.07729
4	0.42	2.5	15	0.255	0.105943	0.12737
5	0.42	2.5	20	0.340	0.140065	0.19223
6	0.42	2.5	25	0.425	0.173175	0.27875
7	0.42	2.5	30	0.510	0.205034	0.39596
8	0.42	2.5	35	0.595	0.235414	0.55637
9	0.42	2.5	40	0.680	0.264093	0.77808

Appendix B

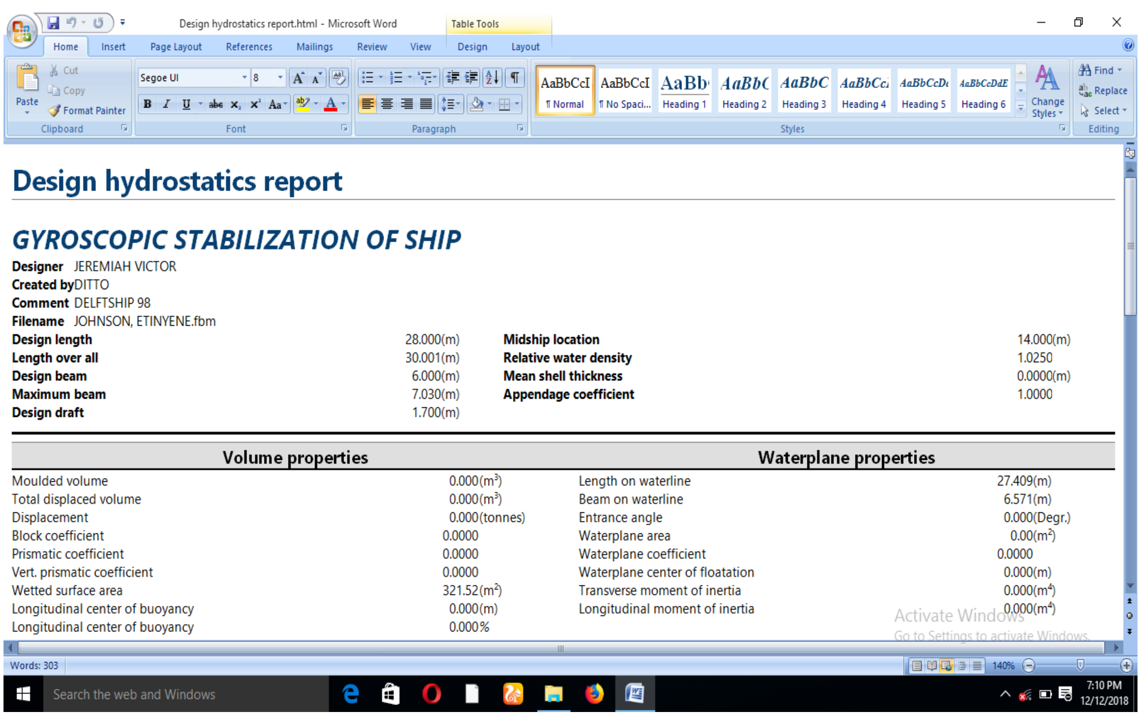
Minitab17 calculation for the new roll amplitude



	C1	C2	C3	C4	C5	C6	C7	C8	C9
	N (KNs)	Δ (Kg)	Øo (degree	Øo (radian)	g (m/s2)	Gm (m)	T (sec)	φ (radian)	φ (degree)
2	70000	117000	40	0.68	9.81	0.42	7	0.163913	9.3915
3	70000	117000	30	0.51	9.81	0.42	8	0.111350	6.3799
4	70000	117000	20	0.34	9.81	0.42	9	0.067615	3.8740
5	70000	117000	10	0.17	9.81	0.42	10	0.030872	1.7688

Appendix C

Delft ship design hydrostatic report for MV Ofure



Design hydrostatics report

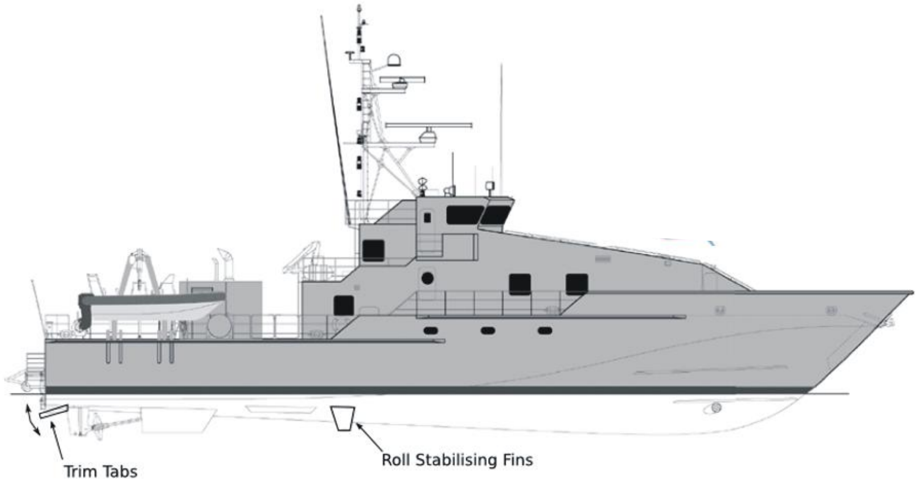
GYROSCOPIC STABILIZATION OF SHIP

Designer JEREMIAH VICTOR
Created by DITTO
Comment DELFTSHIP 98
Filename JOHNSON, ETINYENE.fbm

Design length	28.000(m)	**Midship location**	14.000(m)
Length over all	30.001(m)	**Relative water density**	1.0250
Design beam	6.000(m)	**Mean shell thickness**	0.0000(m)
Maximum beam	7.030(m)	**Appendage coefficient**	1.0000
Design draft	1.700(m)		

Volume properties		Waterplane properties	
Moulded volume	0.000(m^3)	Length on waterline	27.409(m)
Total displaced volume	0.000(m^3)	Beam on waterline	6.571(m)
Displacement	0.000(tonnes)	Entrance angle	0.000(Degr.)
Block coefficient	0.0000	Waterplane area	0.00(m^2)
Prismatic coefficient	0.0000	Waterplane coefficient	0.0000
Vert. prismatic coefficient	0.0000	Waterplane center of floatation	0.000(m)
Wetted surface area	321.52(m^2)	Transverse moment of inertia	0.000(m^4)
Longitudinal center of buoyancy	0.000(m)	Longitudinal moment of inertia	0.000(m^4)
Longitudinal center of buoyancy	0.000%		

Appendix D
Schematic diagram of MV Ofure



REFERENCE

1. Alex, K. et al (2017). Gyroscopic Stabilization of Rolling Motion in Simplified Marine Hull Model. IEEE 7th International Conference on Underwater Systems Technology: Theory and practice.
2. Arnold & Maunder, L. (1961): Gyrodynamics and its Engineering Application, Academic press, New York and London.
3. Byeongwon, P. et al (2018). Study on the Estimation Methods of Roll Damping Coefficients Using Designed Excitation Device for Harmonic Roll Motion. 28th International Ocean and Polar Engineering Conference. Pp 10-15, Saporo, Japan.
4. Chakrabarau, S. (2007) Empirical Calculation of Roll Damping for Ships and Barges. Publication of Ocean Engineering. Vol.28 pp.915-932.
5. Contento, G. and Francescutto, A. (1996) Effectiveness of Constant Roll Motion Equation. Publication of Ocean Engineering. Vol. 23(7) pp.597-618.
6. Crossland, P. (2000). The Effect of Roll Stabilization Controllers on Warships Operational Performance in 5th IFAC Conference on Maneuvering and Control of Marine Craft. Pp31-37.
7. Donarie, A. and Perez, T. (2013). Energy-Based Non-Linear Control of Ship Roll Gyro Stabilizer with Procession Angle Constants.In 9th IFAC International Conference on Control Appication in Marine Systems. Osaka, Japan.
8. Fossen, T. (2011). Handbook of Marine Craft Hydrodynamics and Control, Wiley. Retrieved from: http.www.brighthubengineering.org (6th August, 2018).
9. Gilmar, T. (1984). Modern Ship Design Anapolis MD, USA. U.S Naval Institute. Pp 271.
10. Perez, T and Blanke, M (2012). Ship Roll Damping Control. Annual Reviews in Control, 36(1), 1367 – 5788.
11. Perez, T. (2005). Ship Motion Control Advances Industrial Control, Spinger-Verlag, London.
12. Perez, T. and Steinmann, P. (2008). Advances in Gyro-stabilization of Vessel Roll Motion in Pacific International Maritime Conference (IMC), Sydney, Australia.
13. Perez, T. and Steinmann, P. (2009). Analysis of Ship Roll Gyro Stabilizer Control. In 8th IFAC International Conference on Maneouring and Control of Marine Craft. September, Guaraija, Brazil.
14. Sellars, F. and Martins, J. (1992(. Selection and Evaluation of Ship roll Stabilization Systems. Marine Technology of Ship Roll Stabilization Systems. Marine Technology SNAME, 29 (2), 84 – 101.
15. Sir White W. (1907). Experiments with Dr. Schlicks's Gyroscopic Apparatus for Steadying Ships. Transactions of the Institution of Naval Architects INA.
16. Steinmann, P. and Perez, T. (2009). Gyrostabilized High Speed Trimarans in RINA International Conference on Innovations in High Speed Marine Vessels. Freemantle. Australia.
17. Taylan, M. (1996). Nonlinear Roll Motion of Ships in Beam Waves. Bulletin of the Instanbul Technical University (4a). pp. 459-479.
18. Taylan, M. (2000). The Effect of Nonlinear Damping and Restoring in Ship Rolling. Publication of Ocean Engineering vol. 27. Pp 921-932.